REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE:	3. REPORT TYPE AND DATES COVERED Final Report 1-Feb-2005 - 31-Jan-2006

4. TITLE AND SUBTITLE High Performance Terahertz Detectors Based on Granting Gated Double-Quantum Well	5. FUNDING NUMBERS W911NF0510031
6. AUTHORS Gregory Aizin	8. PERFORMING ORGANIZATION REPORT NUMBER
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES CUNY (City College of New York) 138 Street @ Convert Avenue 79 Fifth Ave. New York, NY 10031 -	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	10. SPONSORING / MONITORING AGENCY REPORT NUMBER 45460-EL-H.1

11. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12. DISTRIBUTION AVAILIBILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for Public Release; Distribution Unlimited	

13. ABSTRACT (Maximum 200 words)

The abstract is below since many authors do not follow the 200 word limit

14. SUBJECT TERMS	15. NUMBER OF PAGES
terahertz electromagnetic radiation, terahertz detector, field-effect transistor, two-dimensional electron gas, two-dimensional plasmon	Unknown due to possible attachments
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION ON THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev .2-89)
Prescribed by ANSI Std.
239-18 298-102

Report Title

PLASMON ENHANCED ELECTRON DRAG AND TERAHERTZ PHOTOCONDUCTANCE IN A GRATING-GATED FIELD-EFFECT TRANSISTOR WITH TWO-DIMENSIONAL ELECTRON CHANNEL

ABSTRACT

The specific goal for the 1st year was to develop a physical model of the interaction between THz EM radiation and 2D electron channel of the grating-gated field-effect transistor. This physical model has been developed. The model predicts and allows to calculate photo induced dc correction to the sourse-drain voltage measured in experiment. Calculations demonstrate that dc photovoltage has resonant peaks at plasmon frequencies. Dependence of the peak positions, shape, and amplitude on the frequency, gate voltage, temperature, and FET geometry has been found. Distributions of the non-equilibrium electron density, electric fields, and currents in the 2D channel at resonance have been calculated. The results are in very good qualitative agreement with experiment. Plans for the coming year include numerical simulation of the dc photoresponce for various system designs in order to optimize device parameters and assess its potential as a THz detector.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Papers presented at meetings, but not published in conference proceedings (N/A for none)

1. G.R. Aizin, L.G. Mourokh, S.J. Allen, M.C. Wanke "Resonant Terahertz Photoresistance in Laterally Modulated Two-dimensional Electron Systems", presented at the 16th International Conference on Electronic Properties of Two-dimensional Systems (EP2DS-16), July 10-15, 2005, Albuquerque, NM USA.

2. G.R. Aizin, L.G. Mourokh, S.J. Allen, M.C. Wanke "Anomalous Temperature Dependence of the Resonant Terahertz Photoresistance in Laterally Modulated Two-dimensional Electron Systems", presented at the 14th International Conference on Nonequilibrium Carrier Dynamics in Semiconductors (HCIS-14), July 24-29, 2005, Chicago, IL USA.

3. G.R. Aizin, V.V. Popov, O.V. Polischuk "Plasmon resonances in the terahertz photoresponse of homogeneous 2D electron system with grating gate", accepted at 28th International Conference on the Physics of Semiconductors, Vienna, Austria, July 24-28, 2006

Number of Papers not Published: 3.00

(d) Manuscripts

G.R. Aizin, V.V. Popov, O.V. Polischuk "Plasmon enhanced electron drag and terahertz photoconductance in a grating-gated field-effect transistor with two-dimensional electron channel", to be submitted to Applied Physics letters

Number of Manuscripts: 1.00

Number of Inventions:

Graduate Students

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Under Graduate students supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

1 a. Vyacheslav V. Popov

1 b. Saratov Division, Institute of Radioe
of the Russian Academy of Sciences
Saratov 410019

Sub Contractor Numbers (c):

Patent Clause Number (d-1):

Patent Date (d-2):

Work Description (e): To perform computer modeling of the interaction of an external electromagnetic wave wi

Sub Contract Award Date (f-1): 6/1/2005 12:00:00AM

Sub Contract Est Completion Date(f-2): 1/31/2006 12:00:00AM

---

1 a. Lev Murokh

1 b. Department of Physics and Engineer
Stevens Institute of Technology
Hoboken NJ 07030

Sub Contractor Numbers (c):

Patent Clause Number (d-1):

Patent Date (d-2):

Work Description (e): To perform numerical analysis of the interaction of electron plasma waves in two-dimens

Sub Contract Award Date (f-1): 6/1/2005 12:00:00AM

Sub Contract Est Completion Date(f-2): 11/1/2005 12:00:00AM

Inventions (DD882)

Plasmon enhanced electron drag and terahertz photoconductance in a grating-gated field-effect transistor with two-dimensional electron channel

I. MOTIVATION AND STATEMENT OF THE PROBLEM.

The present study is motivated by the recent observations of the plasmon resonances in the THz photoconductivity of two-dimensional (2D) electron channel in the grating-gated field-effect transistor (FET) [1,2]. The original experiments were performed in the double-quantum-well semiconductor structures [1]. However, very recent experiments revealed similar effects in the single quantum wells [2]. In these experiments grating-gated FET was irradiated by the electromagnetic (EM) wave of terahertz frequency at normal incidence. The EM wave was linearly polarized in the direction perpendicular to the grating fingers. Source-drain dc current was applied in the same direction and the dc photoresponse (linear in the THz power) was measured as a function of electron density (controlled by the gate voltage), terahertz frequency, and temperature. Strong resonant peaks have been observed in the photoresponse as a function of the electron density. Dependence of the peak positions on the electron density, frequency and the wave number (determined by the grating period) allowed to reliably identify these peaks with collective plasma excitations in the 2D electron gas. However, physical mechanism responsible for the changes in the photoconductance of this system remained unknown.

We present a theory of plasmon enhanced photoconductance in a homogeneous 2D electron channel in the grating-gated field-effect transistor irradiated by an electromagnetic wave of terahertz frequency. We determine photo induced dc correction to the source-drain voltage and demonstrate that it has resonant peaks when the frequency of an external radiation coincides with 2D plasmon frequencies. The dc photoresponse is shown to depend on the asymmetric electron drag in the 2D channel with applied dc bias current. In high mobility samples, amplitude of the photoresponse resonant peak has non-monotonic temperature dependence with maximum at elevated temperatures. Our results are in good qualitative agreement with recent experiments.

II. THEORY OF THE DC PHOTORESPONSE IN THE GRATING-GATED FET

In a series of recent experiments [1-6] it has been demonstrated that collective charge density oscillations (plasmons) in 2D electron systems (2DES) can be used for detection of THz EM radiation. When the plasmon wave in 2DES is excited by an external EM radiation the induced ac electric fields can be converted into the measurable dc signal via some non-linear conversion mechanism. Typical frequencies of plasmons in 2DES lie in the sub-THz and THz range and can be easily tuned by changing the electron density in the gated structures. Excitation of the plasmons by an external EM field is the resonant effect provided that $\omega_p \tau >> 1$, where ω_p is the plasmon frequency and τ is the momentum relaxation time. These features make low-dimensional semiconductor

structures very promising candidate in regard to the fabrication of the THz detector with tunable frequency control and narrow spectral bandwidth.

Recently explored plasmon resonant THz detectors use plasmon excitations in the 2D channel of the submicron-size GaAs-based high electron mobility field-effect transistor (HEMT) [3-5] and in the grating-gated 2D GaAs/AlGaAs field effect transistor (FET) [1,2]. Alternative approach based on excitation of the edge magnetoplasmons has been developed in Ref. [6].

In the resonant THz detector based on GaAs-HEMT a short gated 2D electron channel of submicron size serves as a resonant cavity for the plasma waves. Rectification, i.e. generation of the dc signal between the drain and source contacts, occurs due to asymmetric boundary conditions at the source and the drain sides of the 2D channel [7]. Because of its small size, such a detector represents a lumped load for the incoming THz radiation and requires special antenna elements to couple the detector to an external THz EM field.

Terahertz photovoltaic as well as photoconductive responses in a distributed grating-gated GaAs/AlGaAs heterostructure FET have been observed in Refs. [1,2]. Measurements were made in the double and single quantum well structures of relatively large area (typically 2×2 mm^2). In this geometry, grating gate covering the structure acts as an effective receiving antenna for incoming THz radiation and couples an external EM field to the plasmon excitations in the 2D channel. This gate was also used to control and modulate electron density in the channel. The resonant dc voltage was measured between the source and drain contacts when constant source-drain current was applied. Experimental data clearly demonstrate that the resonant photoresponse is connected with excitation of plasmons in the 2D electron channel. This conclusion was confirmed in Refs. [8,9] where it was shown that the resonant peaks in the photoresponse correlate with plasmon resonances in the channel under the grating gate fingers. In this structure, boundary conditions at the opposite edges of the grating gate fingers are symmetric and can not produce signal rectification.

In this report, we present a theory of photoconductance in a homogeneous 2D electron channel in the grating-gated FET interacting with an external THz EM field. We demonstrate that dc photoresponse (ac signal rectification) is produced by the plasmon enhanced asymmetric electron drag in the grating-gated 2D channel with applied dc bias current. Resonant peaks in the dc photoresponse are formed when the frequency of external radiation coincides with the 2D plasmon frequencies. Calculated photoresponse spectra reproduce many basic characteristic features of the THz photoresponse observed in Refs. [1,2].

We assume that 2DES in the FET channel can be described by the hydrodynamic equations (Euler equation and equation of continuity) and consider an interaction of the 2D electron fluid with normally incident external EM wave of frequency ω_0 polarized perpendicular to the grating fingers (x-axis). The wave is modulated in the x-direction by the grating gate fingers so that the total self-consistent electric field in the 2D plane is $E_0 + E(x,t)$ where E_0 is constant bias field and $E(x,t) = E(x+l,t)$ is spatially periodic

THz correction, l is the grating period. Local density $n(x,t)$ and velocity $\upsilon(x,t)$ in the 2D electron fluid can also be represented as $n(x,t) = n_0 + \delta n(x,t)$ and $\upsilon(x,t) = \upsilon_0 + \delta\upsilon(x,t)$, where δn and $\delta\upsilon$ are spatially periodic THz corrections to the equilibrium 2D electron density n_0 and constant drift velocity $\upsilon_0 = -e\tau E_0 / m^*$, with $-e$ and m^* being an electron charge and effective mass, respectively. We represent the total current, $j(x,t) = -en(x,t)\upsilon(x,t)$, as $j(x,t) = j_0 + \delta j(x,t)$ where $j_0 = \sigma_0 E_0$ is constant applied dc current, $\sigma_0 = e^2 n_0 \tau / m^*$, and $\delta j(x,t)$ is local spatially periodic THz current correction. Our quantity of interest is space and time average of the THz current correction δj_{00}.

Equations for the Fourier transformed density and velocity corrections $\delta n_{\omega q}$ and $\delta\upsilon_{\omega q}$ can be obtained from the hydrodynamic equations for the 2D fluid. These non-linear equations couple different harmonics with frequencies $n\omega_0$. We assume that the amplitude of an external THz wave is relatively small and consider photoresponse linear in the THz power. (This type of photoresponse was reported in Refs. [1,2].) In this case terms with frequencies $n\omega_0$ ($n > 1$) can be omitted since they contribute to the photoresponse at the higher orders in the THz power [7]. In this approximation solution of the linearized hydrodynamic equations for $\delta n_{\omega q}$ and $\delta\upsilon_{\omega q}$ yields

$$\delta n_{\omega q} = -\frac{q}{e\omega}\sigma(\omega,q)E_{\omega q} \ , \tag{1}$$

and

$$\delta j_{00} = \frac{e^2\tau}{m^*}\sum_{\omega=\pm\omega_0}\sum_q \delta n_{\omega q} E_{-\omega -q} \ , \tag{2}$$

where

$$\sigma(\omega,q) = \sigma_0 \frac{i\omega\nu}{(\omega - q\upsilon_0)(\omega - q\upsilon_0 + i\nu)} \ , \tag{3}$$

is the dynamical conductivity of a drifting 2D electron fluid [10] and $\nu = 1/\tau$. In the constant bias current regime THz illumination of the grating-gated FET results in an additional dc photovoltage δU_0 developed between the source and drain contacts: $\delta U_0 = -\delta j_{00} L / \sigma_0$ where L is the channel length. This photovoltage was measured as a photoresponse in Refs.[1,2]. Combining Eqs. (1)- (3) we finally obtain

$$\delta U_0 = 2L\frac{e\nu}{m^*}\sum_q \frac{q\left|E_q\right|^2}{(\omega_0 - q\upsilon_0)\left[(\omega_0 - q\upsilon_0)^2 + \nu^2\right]} \ , \tag{4}$$

where $E_q \equiv E_{\omega_0 q}$ is the Fourier harmonic of the total self-consistent in-plane electric field of frequency ω_0 with wave vector $q = 2\pi m / l$, $m = 0, \pm 1, \pm 2, ...$.

Physical mechanism of the dc photoresponse can be explained based on Eq. (4). Normally incident THz radiation is spatially modulated by the grating gate and induces periodic electric field profile in the 2D plane. This profile represents a longitudinal

standing electric wave. Each traveling component of the standing electric wave with amplitude E_q produces electron drag in the direction of its wave vector q. The net drag is determined by the sum of all partial contributions in Eq. (4). At zero bias current ($\upsilon_0 = 0$), $|E_q|$ is equal to $|E_{-q}|$ for symmetry reasons, and the electron drag due to components of the standing waves with wave vectors q and $-q$ traveling in opposite directions cancel each other resulting in the zero photoresponse, see Eq. (4). Constant source-drain current breaks the symmetry of these two components ($|E_q| \neq |E_{-q}|$ as shown below) giving rise to the non-zero net electron drag in the direction of the traveling electric field component with larger amplitude. The difference between $|E_q|$ and $|E_{-q}|$ depends on the parameter $q\upsilon_0 / \omega_0$ which is very small in the experiment [1,2]. In this case dc photoresponse should also be very small. However, the situation changes near the plasmon resonance where Fourier amplitudes E_q are resonantly enhanced due to excitation of the plasma waves in the 2D channel. These resonant photoresponse peaks have been measured in Refs. [1,2]. At plasmon resonance with wave vector q the Fourier amplitude E_q of the total electric field is enhanced in compared with the external THz electric field amplitude E_q^{ext} as $|E_q| = Q|E_q^{ext}|$, where $Q = \omega_p / \Delta\omega$ is the plasmon resonance quality factor, and $\Delta\omega$ is the full width of the plasmon resonance line at half of its maximum (FWHM). The FWHM is determined by both dissipative (v) and radiative (γ_r) damping of the plasmon mode: $\Delta\omega = v + \gamma_r$. The radiative damping is proportional to the equilibrium 2D electron density and also depends on the coupling of the plasmon mode to the EM radiation [8,11]. Dissipative damping is determined by the mobility and increases with the temperature. In the high-mobility samples, the values of v and γ_r can be comparable in magnitude [11]. These results can be used to explain non-monotonic temperature dependence of the photoresponse peak amplitude observed in [1,2]. Equation (4) written in terms of the external THz electric field yields $\delta U_0 \sim v/(v+\gamma_r)^2$. If at low temperatures $v < \gamma_r$, the photoresponse increases with the temperature taking the maximum value when $v = \gamma_r$ and then decreases again at higher temperatures. Under condition $v = \gamma_r$, THz absorbance at the plasmon resonance also takes the maximum value [8]. Enhancement of both THz absorbance and photoresponse occurs due to the maximum pumping of the THz power into the 2D channel at $v = \gamma_r$. In fact, this condition implies impedance matching.

We calculated the components of the total electric field E_q and the photoresponse δU_0 in Eq. (4) numerically using self-consistent electrodynamic approach developed in Ref. [8]. In our calculations we used the following parameters for the grating-gated GaAs/AlGaAs FET: $L = 2$ mm, $l = 4\,\mu$m, $n_0 = 2.57\times10^{11}$ cm^{-2}, $j_0 = 0.05$ A/m, the width of the grating gate finger $w = 2\,\mu$m, the distance between the grating gate and the 2D channel $d = 0.4\,\mu$m, input THz radiation intensity is 1W/cm^2 with the device area 2×2 mm^2. Our numerical results for the dc photoresponse as a function of the THz frequency near the

first plasmon resonance ($q = \pm 2\pi / l$) are presented in Fig. 1. The photoresponse curves at different values of τ demonstrate a non-monotonic behavior of the resonant peak height with the maximum at $\tau = 6.67 \times 10^{-11}$ s. Besides the main resonant peak near the plasmon frequency of 375 GHz additional resonant feature was found near the frequency of 430 GHz. This result can be explained as follows. In homogeneous 2DES with metal grating gate each plasmon mode with wave vector $q = 2\pi m / l$ splits into two modes of different frequencies ω^- and ω^+. At zero 2D electron drift ω^-- and ω^+-modes have even ($E_q = E_{-q}$) and odd ($E_q = -E_{-q}$) in-plane electric field distribution under the grating gate finger, respectively [12,13]. Because of the symmetry, only an even mode is optically active and can be excited by an external EM field. Finite bias current breaks the symmetry of the in-plane electric field distribution for both modes and makes ω^+-mode optically active so that both modes contribute to the dc photoresponse. The main resonant peak in Fig. 1 corresponds to the ω^--mode whereas additional resonant feature at larger frequency is related to the ω^+-mode.

In Fig. 2, Fourier amplitudes of the total in-plane electric field $|E_{\pm 1}|$ are shown as a function of the THz frequency. Field amplitudes $|E_{\pm 1}|$ as well as the difference $|E_{+1}|^2 - |E_{-1}|^2$ responsible for the photoresponse peak are resonantly enhanced near the first plasmon resonance of the ω^--mode. Similar dependence for the ω^+-resonance is shown in the Fig. 1 insert. Here the difference $|E_{+1}| - |E_{-1}|$ changes sign at the plasmon resonance giving rise to the photoresponse peaks of opposite sign in Fig. 1.

Coupling of an external THz field to the plasmons becomes stronger for the grating gates with narrow slits between the fingers [11-13]. Stronger coupling results in the increased height of the photoresponse peaks. In Fig. 3, dc photoresponse is shown as a function of the gate voltage at two different frequencies for the same grating-gated FET structure as discussed above but with $w = 3.6\mu$m. In this calculation an equilibrium 2D electron density was related to the gate voltage using the parallel plate capacitor model, and spatial modulation of the electron density was neglected. The latter approximation is justified when $l - w << l$ and $d << l$. For narrow grating slits the splitting of the ω^-- and ω^+-modes decreases [12,13], and both plasmon resonances merge producing one combined resonance of complex shape shown in Fig. 3. One should point out that the higher order plasmon resonances give larger photoresponse in Fig. 3 due to increased wave vectors q involved, i.e. stronger spatial inhomogeneity of the induced electron density.

The dc photoresponse also increases with the bias current. At larger values of υ_0 the difference between E_q and E_{-q} increases. The plasmon frequencies ω^- and ω^+ also change due to Doppler shift [14]. At low drift velocities corresponding to the small bias currents used in [1,2] the frequency change with υ_0 is small (the so called non-linear Doppler shift [15]). At larger values of υ_0 the plasmon frequencies demonstrate a linear

Doppler shift [15,16]. In this regime, near the plasmon resonance the resonant Fourier harmonics $E_{\pm q}$ are concentrated in one of the two split plasmon modes: $E_q \to 0$, $E_{-q} \neq 0$ in the ω^--resonance and $E_{-q} \to 0$, $E_q \neq 0$ in the ω^+-resonance, resulting in the enhanced photoresponse. These conclusions are demonstrated in Fig. 4 where dc photoresponse is shown as a function of frequency in the linear Doppler shift regime for the current density 50 A/m and two different values of w/l.

Physical model developed above explains qualitatively many characteristic features of the dc photoresponse in the grating-gated GaAs/AlGaAs FET measured in Refs.[1,2]. However, experimental dc photoresponse is much stronger than the one predicted in our model. This quantitative discrepancy can be attributed to the equilibrium density modulation induced by the grating gate in the experiment [1,2]. This effect, not included into the present model, significantly increases the coupling of an external THz field to the plasmons and can modify an in-plane electric field distribution, both contributing to the stronger photoresponse. This conclusion is confirmed by the fact that the maximum photoresponse has been observed when the 2D electron channel was near complete pinch-off [1,2]. Generalization of the theory to include the density modulated electron channels is required to achieve quantitative agreement with the experiment. This work is in progress now.

III. SUMMARY

Physical model of the dc photoresponse in the grating-gated FET irradiated by THz EM wave is developed. The model predicts resonant peaks in the dc photovoltage at 2D plasmon frequencies. It is demonstrated that both positive and negative peaks can be observed dependent on the device geometry. The peak amplitudes are shown to have non-monotonic temperature dependence with maximum at elevated temperatures. The resonant peak enhancement is predicted at larger bias currents. The theoretical results explain many experimental observations and can be used to optimize performance of the THz detector based on the grating-gated FET.

BIBLIOGRAPHY

1. X. G. Peralta, S. J. Allen, M. C. Wanke, N. B. Harff, J. A. Simmons, M. P. Lilly, J. A. Reno , P. J. Burke, and J. P. Eisenstein, Appl. Phys. Lett., **81**, 1627 (2002)
2. E. A. Shaner, Mark Lee, M. C. Wanke, A. D. Grine, J. L. Reno, S. J. Allen, Appl. Phys. Lett., **87**, 193507 (2005).
3. W. Knap, Y. Deng., S. Rumyantsev, J.-Q. Lu, M.S. Shur, C.A.Saylor, and L.C. Brunel, Appl. Phys. Lett. **80**, 3433 (2002).
4. D. Veksler, F. Teppe, A. P. Dmitriev, V. Yu. Kachorovskii, W. Knap, M. S. Shur. Phys. Rev. B, **73**, 125328 (2006) and references therein.
5. T. Otsuji, M. Hanabe, and O. Ogawara, Appl. Phys. Lett. **85**, 2119 (2004).
6. I. V. Kukushkin, S. A. Mikhailov, J. H. Smet, and K. von Klitzing, Appl. Phys. Lett., **86**, 044101 (2005); P. S. Dorozhkin, S. V. Tovstonog, S. A. Mikhailov, I. V. Kukushkin, J. H. Smet, and K. von Klitzing, *ibid***,** **87**, 092107 (2005).
7. M. Dyakonov and M. Shur, IEEE Trans. Electron Devices **43** 380 (1996).
8. V.V. Popov, O.V. Polischuk, T.V. Teperik, X.G. Peralta, S.J. Allen, N.J.M. Horing, and M.C. Wanke, J. Appl. Phys. **94**, 3556 (2003).
9. V. V. Popov, T. V. Teperik, Yu. N. Zaiko, S. J. Allen, and N. J. M. Horing, Solid-State Electron., **49**, 1049 (2005).
10. A. L. Fetter, Ann. Phys. (NY) **81**, 367 (1973); **88**, 1 (1974).
11. S.A. Mikhailov, Phys. Rev. B **58**, 1517 (1998).
12. O.R.Matov, O.V.Polischuk, and V.V.Popov, Intern. Journ. Infrared and Millimeter Waves **14**, 1455 (1993).
13. R.E. Tyson, D.E. Bangert, and H.P. Hughes, J. Appl. Phys. **76**, 5909 (1994).
14. S. J. Allen, F. Derosa, R. Bhat, G. Dolan, and C. W. Tu, Physica B+C, **134**, 332 (1985).
15. R.E. Tyson, R.J. Stuart, H.P. Hughes, J.E.F. Frost, D.A. Ritchie, and C. Shearwood, Intern. Journ. Infrared and Millimeter Waves **14**, 1237 (1993).
16. O.R.Matov, O.F. Meshkov, O.V.Polischuk, and V.V.Popov, Physica A **247**, 409 (1997).

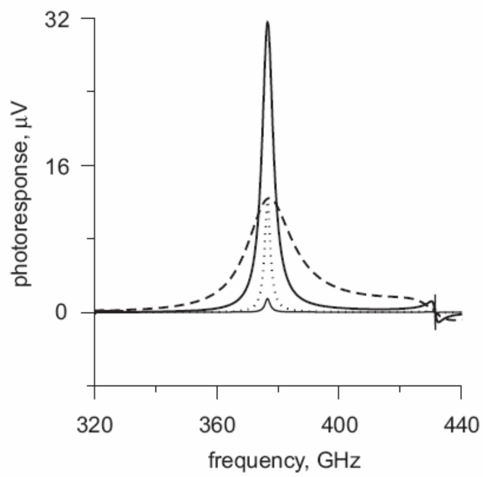

Fig. 1 Photoresponse vs THz frequency for the grating-gated GaAs/AlGaAs FET near the first plasmon resonance for different electron relaxation times: $\tau = 1\times10^{-11}$ s (dashed curve), $\tau = 6.67\times10^{11}$ s (solid curve), $\tau = 6.67\times10^{-10}$ s (dotted curve), and $\tau = 6.67\times10^{-9}$ s (thin solid curve). Bias current density is 0.05 A/m, all other parameters are given in the text. Main peak at 375 GHz corresponds to the even ω^--mode, resonant feature at 430 GHz corresponds to the odd ω^+-mode, see text.

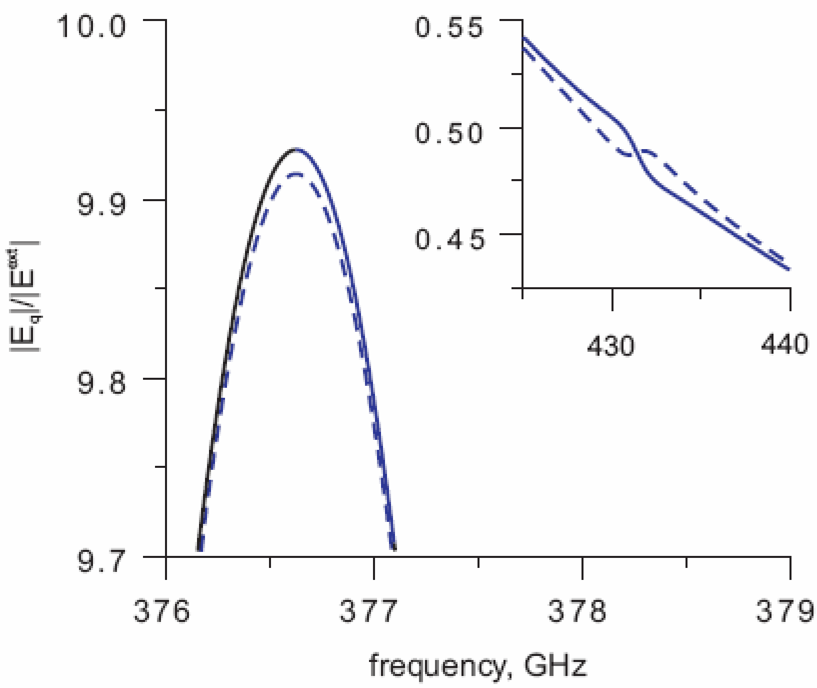

Fig. 2 Frequency dependence of the resonant Fourier amplitudes $|E_{+1}|$ (solid curve) and $|E_{-1}|$ (dashed curve) of the total in-plane electric field in the 2D FET channel near the first plasmon resonance for the even ω^{-}-mode. Data are normalized to the amplitude of the incident THz EM wave E^{i}. $\tau = 6.67\times10^{-11}$ s, other parameters are the same as for Fig.1

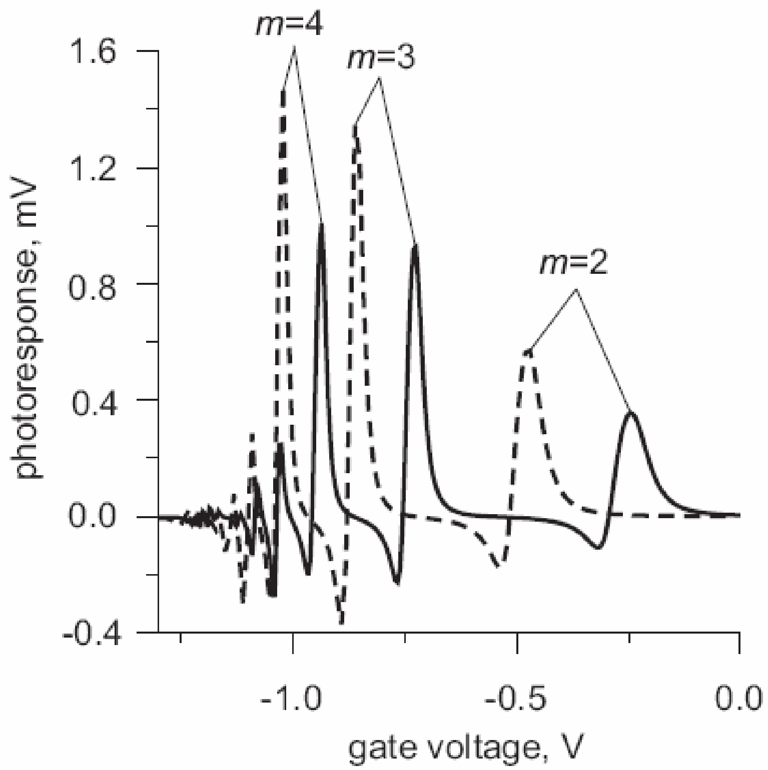

Fig. 3 Photoresponse of the narrow-slit grating-gated FET as a function of the gate voltage for two different frequencies: 450 GHz (solid curve) and 400 GHz (dashed curve). Plasmon mode numbers are indicated, $\tau = 1\times10^{-11}$ s, $w/l = 0.9$, other parameters are the same as for Fig. 1.

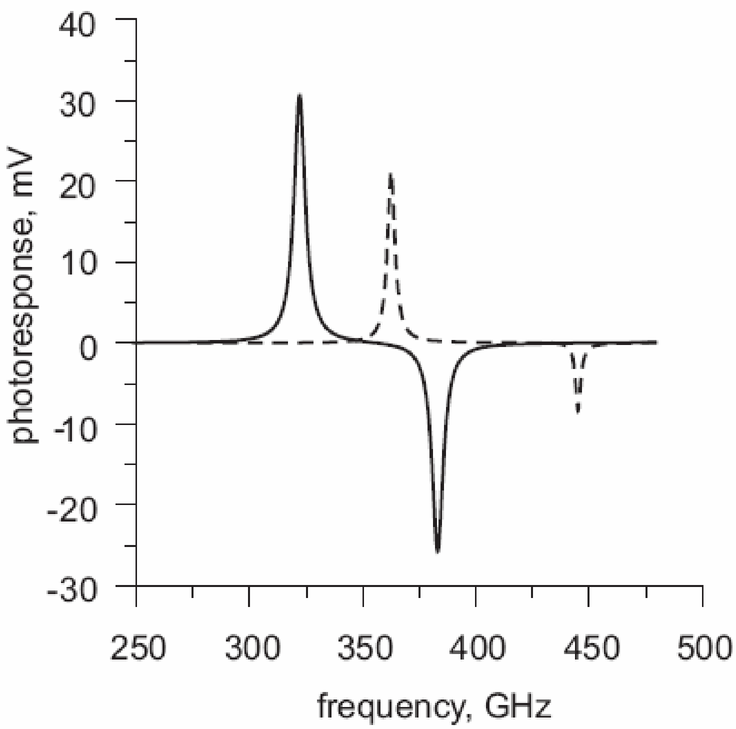

Fig. 4 Photoresponse vs frequency for the grating-gated FET in the linear Doppler shift regime for two different slit widths: $w/l = 0.9$ (solid curve), $w/l = 0.5$ (dashed curve). Bias current density is 50 A/m, $\tau = 6.67 \times 10^{-11}$ s, other parameters are the same as for Fig. 1.